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ALTERNATIVE FUELS

Pat Muzzell, Alternative Fuels Team Leader

June 19, 2009

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Prescribed by ANSI Std Z39-18

Topics

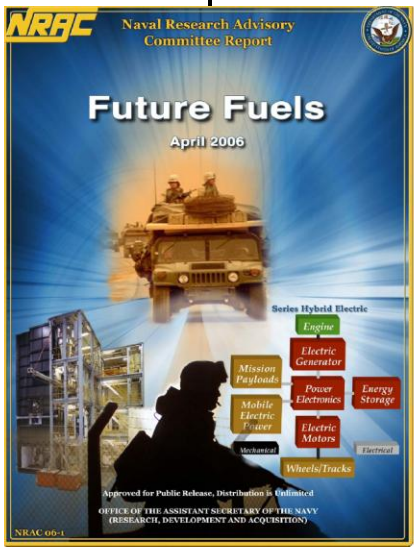
- **Introduction**
  - Transportation Market Evolution
  - Tactical Mobility Fuel
- **Single Fuel in the Battlefield**
  - What is the Single Fuel?
  - Certification / Qualification Pipeline
  - DARPA Alternative Jet Fuels Program
- **Coordinating the Overall Alternative Fuel Qualification Process**
  - Tri-Service POL Users Group
  - Notional Qualification Process
- **Army Alternative Fuels Qualification**
  - Overall
  - Army Aviation Qualification
  - Army Ground Qualification
- **Army Fuel Requirements and the JP-8 Spec**
- **Commercial Aviation Alternative Fuels Initiative (CAAFI)**
  - Roadmaps
  - Fuel Readiness Levels

Transportation Market Evolution

21st Century
Transportation market evolution continues, shaped by heightened concerns about energy security and the environment.

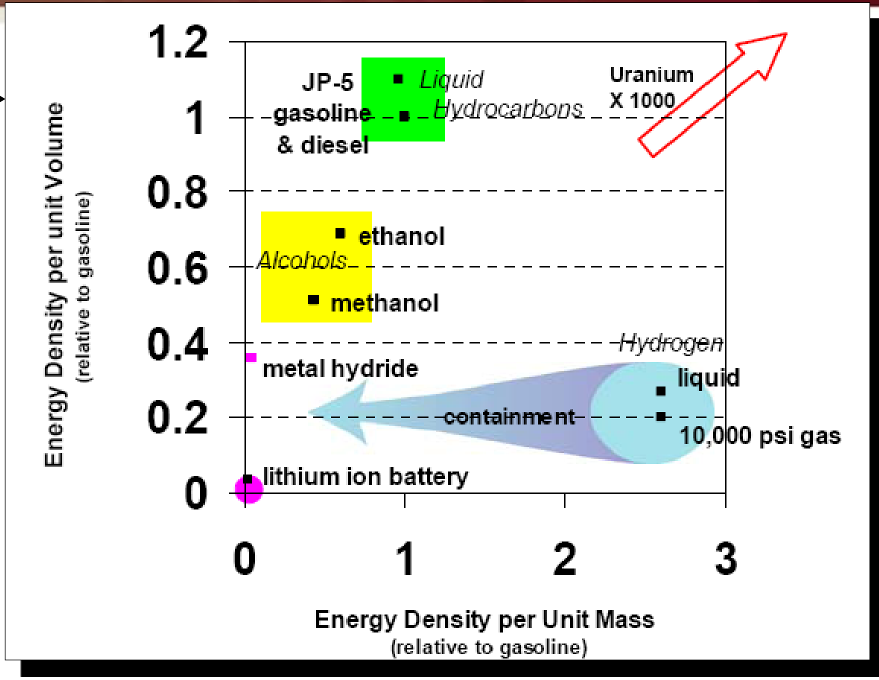
- **Alternative fuels desired in the jet/diesel fuel supply**
- **Changes in fuels supply driven by**
  - Legislation [EPAct 2005, EISA 2007], Exec Orders [EO 13423]
  - USAF Alternative Jet Fuels Program with goal to certify aircraft on alternative jet fuels by 2011
  - Commercial Aviation Alternative Fuels Initiative (CAAFI)
  - Various initiatives to manufacture alternative fuels from diverse sources
- **Army active in assessing emerging changes**
  - Tri-department coordination of alternative fuels qualification efforts

Tactical Mobility Fuel



Naval Research Advisory Committee Panel* Report (April 2006)

* Dr. Walt Bryzik panel member, Chief Scientist, TARDEC (Retired)



Liquid hydrocarbons – ideal fuel for tactical mobility

DOD SINGLE FUEL POLICY

AVIATION KEROSENE GRADE (JP-8)
MIL-DTL-83133
JP-8 (Jet A-1 plus additives) is the primary fuel used for both air and ground equipment in all theaters, overseas and Continental U.S.

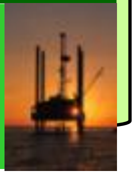
- **Tactical vehicle** designs impose severe limitations on volume and weight
- **Energy density** is therefore the primary consideration for fuel
- **Hydrogen presently unsuitable** as a tactical mobility fuel
  – made from other fuels/resources
  – containment reduces energy density by 10-20X

What is the Single Fuel?

Biomass Energy (renewable)

Fossil Energy (large U.S. resource)

Petroleum Crude Oil (declining discovery / production)



Diverse energy sources

Petroleum based

Non-Petroleum based

Single Fuel in the Battlefield (SFB)*: Kerosene-type (jet) fuels, whether petroleum-based or not, allowed under specs for JP-8 / JP-5 / Jet A-1

Alternative Fuels RDT&E:

- Expand technical database on alternative fuels
- Engage in specifications development for alternative fuels
- Qualify alternative fuels for use in Army tactical / combat equipment and systems

Alternative jet, diesel fuels

- Produced for dual-use (military and commercial)
- Meet specs used by military
- Often blends with petroleum-based fuels

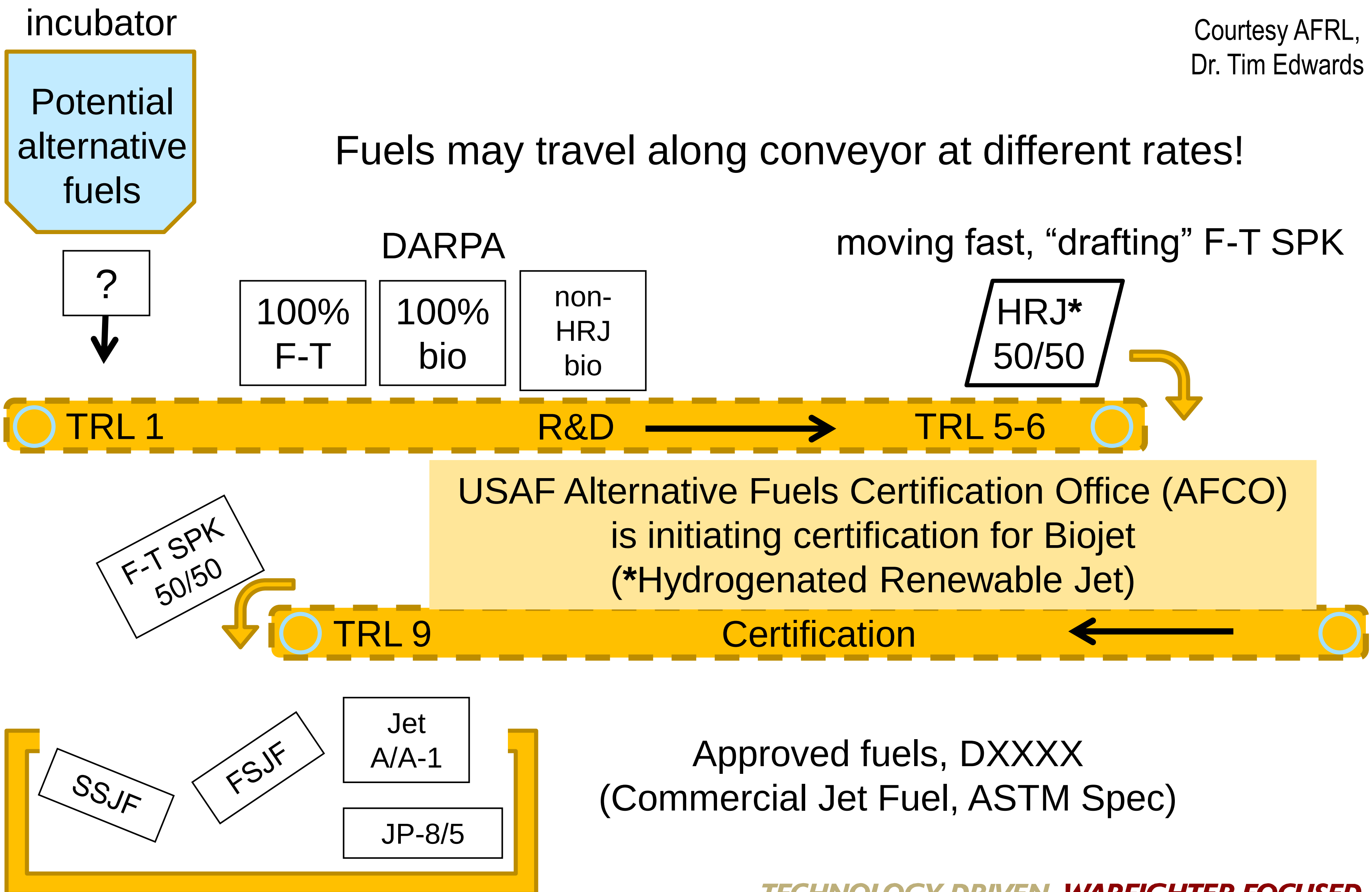
* SFB Policy allows diesel fuel in ground equipment when supplying jet fuel not practicable or cost effective

TARDEC Alternative Fuels Focus

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Unclassified

Certification / Qualification Pipeline



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Hydrogenated Renewable Jet (HRJ) Properties Study - AFRL

- **HRJ properties indistinguishable from F-T SPK**
  - Spec properties (density, freeze, flash, heat of combustion, etc.)
  - Contaminants (metals, oxygenates, etc)
  - Fit-for-purpose properties (lubricity, dielectric, cetane, etc.) (in progress)
  - Combustion operability and emissions (in progress)
  - Material compatibility (in progress)
  - Blend properties (in progress)
- **Issues (same as SPK!)**
  - Density of blend
  - Aromatic content of blend
  - GHG footprint/sustainability
  - Cost (feedstock for HRJ, plant cost for F-T)

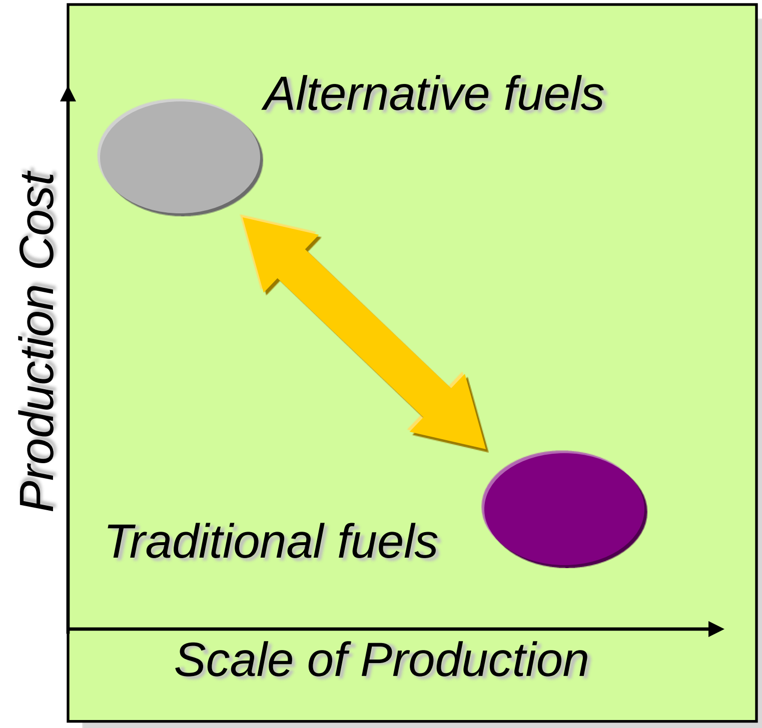
Courtesy AFRL,
Dr. Tim Edwards

DARPA Alternative Jet Fuels

- **Agricultural crop oils** (canola, jatropha, soy, palm, etc.)
  - University of North Dakota EERC
  - UOP
  - General Electric (GE)
  - Swedish Biofuels AB

HRJ (Biojet)

- **Cellulosic and algal feedstocks** that are non-competitive with food material
  - General Atomics ($19.9M)
  - SAIC ($25M)
- Acceptable **coal-derived** fuels
  - $8.4M total
  - proposals due 02 Jun 2009



Can alternative jet fuels be made on large-scale and be cost competitive?

Coordinating Overall Process for Alternative Fuel Qualification

- **Tri-Service POL Users Group**
  - Developing DoD qualification process
    - Includes all stakeholders (e.g., aircraft, ground vehicles/GSE, infrastructure . . .), OEMs
    - Process specified and mandated for alt fuel producers independent of feedstock
    - Requires process be recognized by major fuel specifications, standard agreements

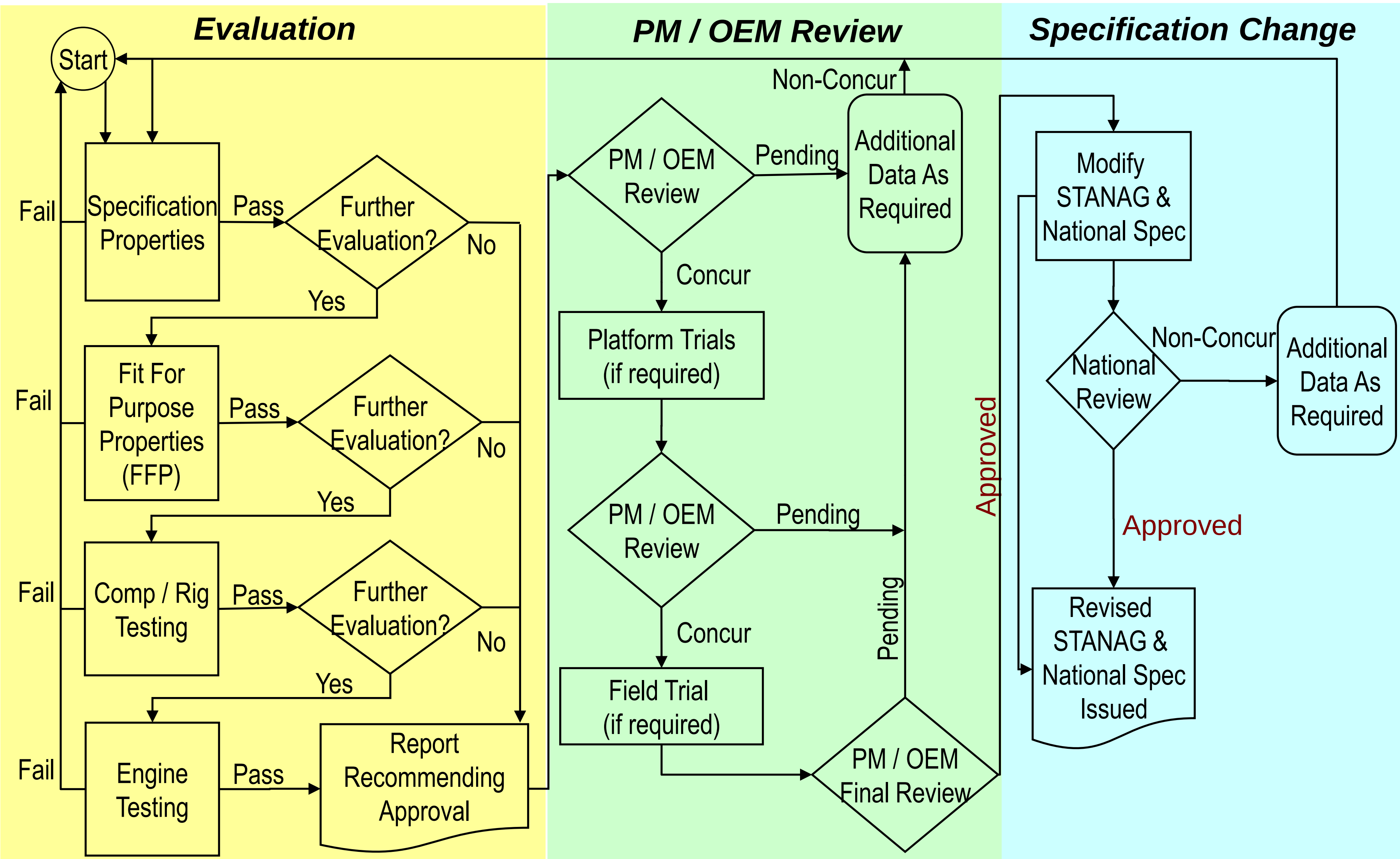
FY08 Focus

  - Synthetic fuels database populated (85%)
  - JP-8 specification FT wording coordinated
  - Continued liaison with DESC SynFuels Working Group
  - Shared Lessons Learned, data and resources

FY09 Challenges

  - Conduct gap analysis – synfuel efforts, expand to biofuels, ID potential joint efforts
  - Increase visibility outside SCP world
  - More awareness needed that group exists, recognition as key OSD asset
  - Development of framework for DoD test and certification process
- **Within Army**
  - Currently in evaluation phase (see process flow chart next slide)
  - Coordination with AMRDEC, need to expand to other key RDEC stakeholders

Alternative Fuel Evaluation & Approval (Notional Qualification Process)



Army Alternative Fuels Qualification

Synfuel Blends

Develop data needed to assess fuel's suitability for use.

Build user knowledge of and confidence in use of fuel.

Laboratory Evaluations → **Component Evaluations** → **System Evaluations** → **Demonstrations**

- **Completed**
  - Fuel chemical composition and properties
  - Materials compatibility evaluations
  - Fuel lubricity evaluations (rotary fuel injection pump)
  - Fuel blends studies
  - Limited component/engine/system testing (ground equipment)
- **In Progress**
  - Engine performance / durability testing (NATO test cycle)
  - Test track evaluation – HMMWV
  - Tactical wheeled vehicle (5x5) pilot field demo
  - Fuel lubricity evaluations (common rail injection system)
  - Cetane - Volatility window studies
- **Planned**
  - Component/engine/system testing and demos **(Army Aviation)**

* Synfuel Blends: blends of Fischer-Tropsch Synthetic Paraffinic Kerosene and JP-8 meeting MIL-DTL-83133F

Army Aviation Qualification

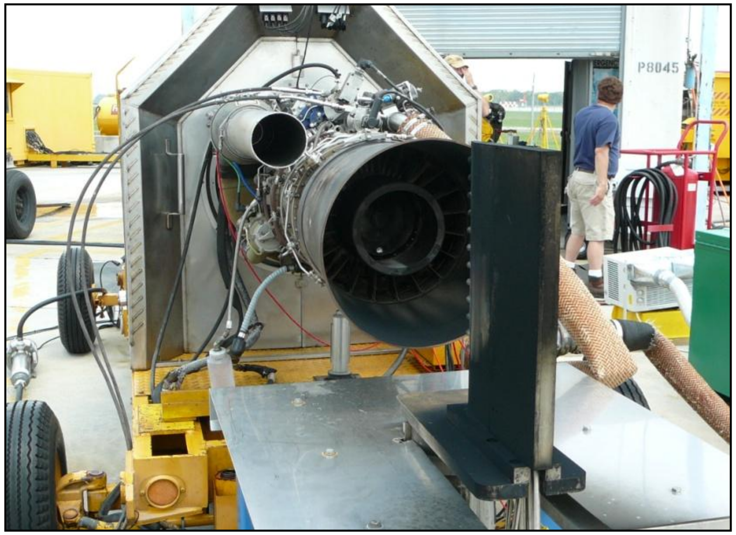
- **Alternative fuels under development for aviation: USAF is lead Service**
- **Certification complete for 50/50 F-T /JP-8 blend on several AF main engines, APUs, and ground support equipment**
- **Streamlined, knowledge-based fuels certification process codified in MIL-HDBK-510**
  - Sufficient for all future aviation fuel certification efforts
  - Maximizes data reuse – streamlines platform certification effort/reduces time & cost
- **MIL-DTL-83133F revised to allow F-T fuels to be a part of the single battlespace fuel (same process can potentially be used new alternative fuels in future)**
- **Alternative fuel blend (up to 50% F-T) to be certified for use in all AF systems by 2011 (SecAF goal)**
- **Army Aviation will leverage AF work to enable reduced certification time and costs for Army Aviation platforms.**
- **Limited alternative fuels testing performed on Army relevant aircraft engines to date: T700-GE-701C**

* Synfuel Blends: blends of Fischer-Tropsch Synthetic Paraffinic Kerosene and JP-8 meeting MIL-DTL-83133F(JP-8 spec)

Army Aviation Relevant Engine Testing

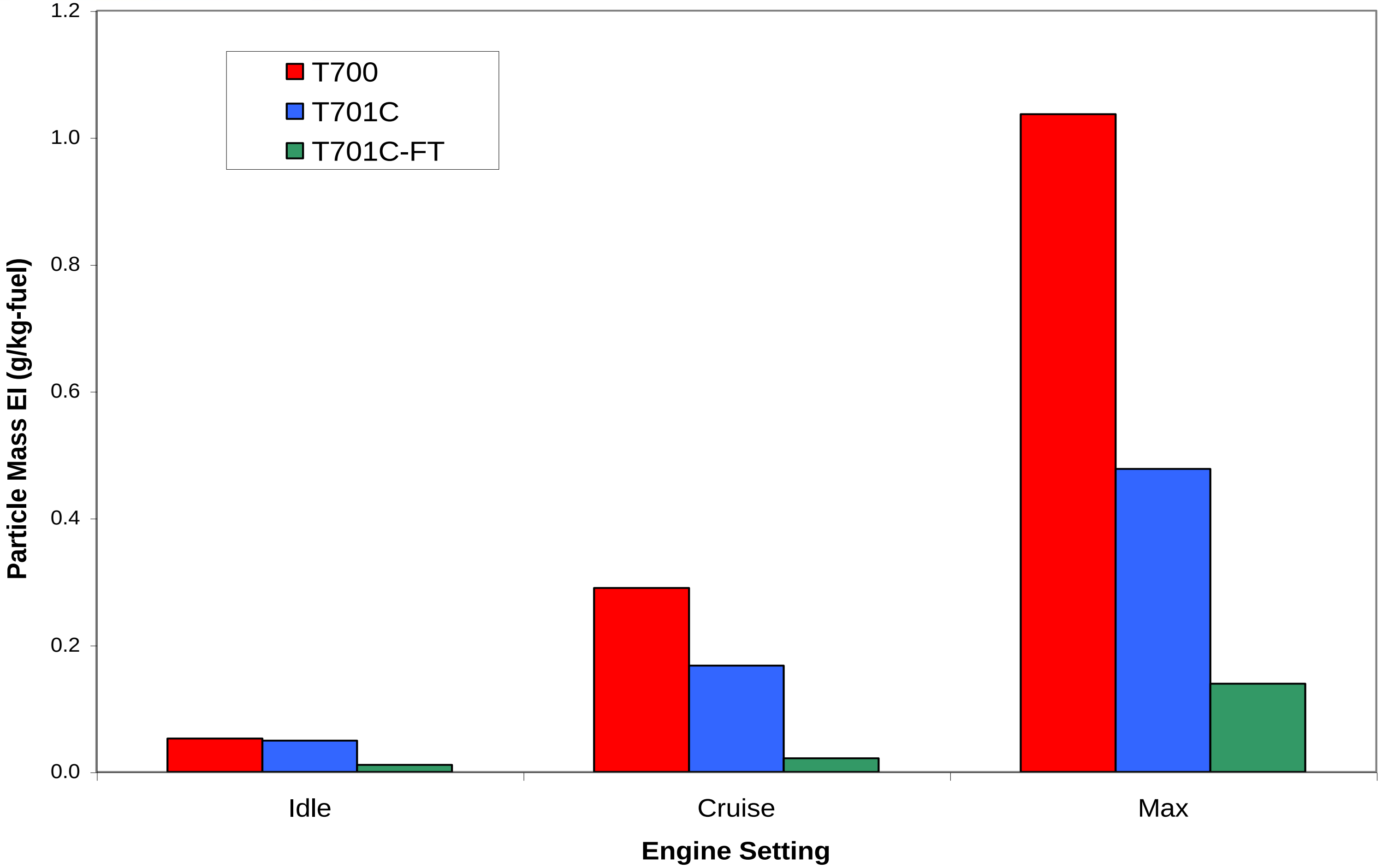
AH-64 Apache

UH-60 Blackhawk



- Tests on one T700 and two T701C engines
- Emissions tests on T701C with JP-8 and neat F-T fuel
- Test under SERDP Project

Army Aviation Relevant Engine Testing



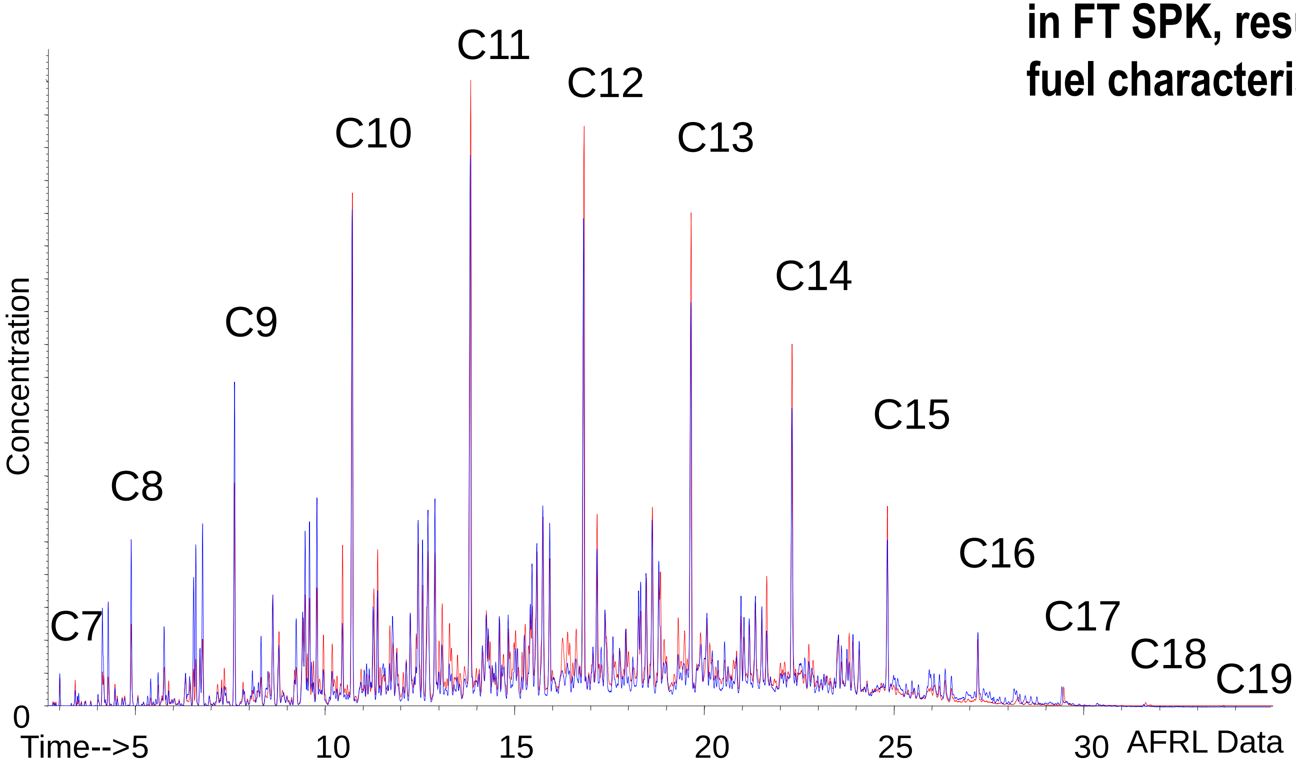
T700-GE-T701C operated with JP-8 and neat FT fuel

Approximately 50% lower particle mass emissions with T701C compared to T700

Reductions of ~75% in particle mass emissions for T701C with neat FT fuel

Properties of Synthetic Paraffinic Kerosene (SPK)

JP-8
Fischer-Tropsch (FT) SPK*



- **Nothing in FT SPK that is not in JP-8**
- **Not all compounds in JP-8 are necessarily in FT SPK, results in some differences in fuel characteristics**

Aromatics:
Lower fuel density and volumetric energy density, higher Cetane No., less solvency

Sulfur:
No exhaust SOx

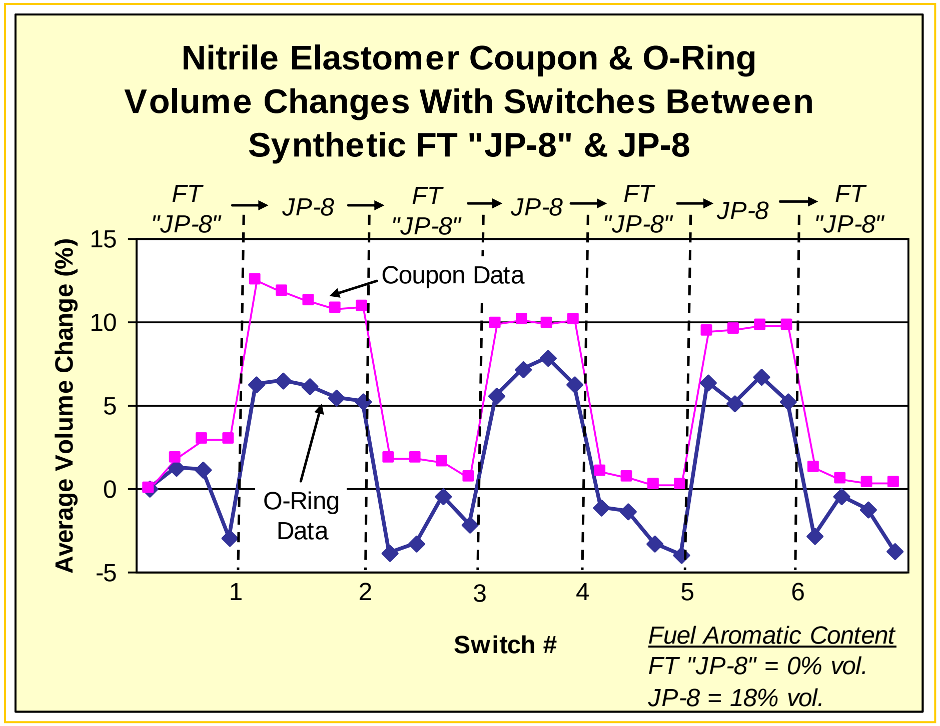
Trace compounds:
Less inherent fuel lubricity

- **Can impact component or engine performance and durability**

***Synthetic-Paraffinic Kerosene:**
Hydrocarbons distributed across the full jet fuel boiling range and having on whole properties suitable for use as an aviation fuel.

Fuel Blends Are Implementation Path

- **TARDEC elastomer compatibility evaluations* supported a "blends implementation path"**
- **Blends of up to 50% by volume FT SPK with JP-8**
  - Blends minimize/eliminate risk of fuel leaks due to change in fuel aromatic content
- **Other aspects supporting a blends implementation path**
  - Production capacity will build slowly
  - Lower energy density of FT SPK



- Nitrile components swell in JP-8, then shrink when switched into FT SPK (FT "JP-8")
- O-ring shrinkage increases risk of sealing failures
- Using unaffected o-ring elastomers or FT SPK in blends with JP-8 are ways to reduce this risk

***SAE Paper 2007-01-1453**

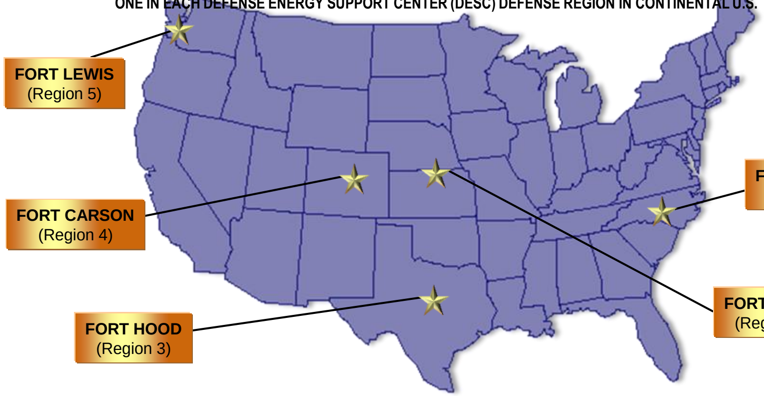
Blends Study

- **FT SPK/JP-8 Blend Properties**
  - Compared properties of blends with typical properties of JP-8 (CONUS, 2004)
  - Determined properties of blends (up to 50% FT SPK) generally fell within typical "property box" of JP-8
  - Study documented in **SAE Paper 2006-01-0702**
- **Follow-on study looked at typical JP-8 in use at five Army installations in CONUS**
  - Determined that at four of the five installations blends with the maximum reduction of 50% by volume petroleum content (JP-8) are possible
  - Study results documented in **2007 IASH Conference Poster** (see next slide)
    - International Association of the Stability, Handling and Use of Liquid Fuels (IASH)

Synfuel Blends Study

FUEL BLENDS STUDY BASED ON JP-8 USED AT FIVE U.S. ARMY FORTS

ONE IN EACH DEFENSE ENERGY SUPPORT CENTER (DESC) DEFENSE REGION IN CONTINENTAL U.S.



50% REDUCTION IN PETROLEUM FUEL (JP-8) POSSIBLE AT FOUR OF THE FIVE FORTS IN STUDY

JP-8: 0.803 kg/L density, 19.7 vol. % aromatics → 50:50 Blend (FT IPK:JP-8), 0.777 kg/L density, 9.9 vol. % aromatics → FORT BRAGG (Region 1)

JP-8: 0.798 kg/L density, 13.9 vol. % aromatics → 42:58 Blend (FT IPK:JP-8), 0.778 kg/L density, 8.0 vol. % aromatics → FORT HOOD (Region 3)

See Example

FT IPK: 0.751 kg/L density, 0.0 vol. % aromatics

JP-8: 0.801 kg/L density, 21.6 vol. % aromatics → 50:50 Blend (FT IPK:JP-8), 0.776 kg/L density, 10.8 vol. % aromatics → FORT CARSON (Region 4)

JP-8: 0.806 kg/L density, 16.5 vol. % aromatics → 50:50 Blend (FT IPK:JP-8), 0.779 kg/L density, 8.3 vol. % aromatics → FORT RILEY (Region 2)

JP-8: 0.815 kg/L density, 20.0 vol. % aromatics → 50:50 Blend (FT IPK:JP-8), 0.783 kg/L density, 10.0 vol. % aromatics → FORT LEWIS (Region 5)

DETERMINING MAXIMUM PERCENTAGE OF FT IPK POSSIBLE IN BLEND WITH GIVEN BATCH OF JP-8

How to Use Chart:

1) Start at left Y-axis with density for given JP-8, read across to density curve (blue) and down to X-axis, note percentage.
2) Then, at right Y-axis with aromatics for given JP-8, read across to aromatics curve (green) and down to X-axis, note percentage.
3) The lower value noted is the maximum FT IPK possible to result in a blend with density ≥ 0.775 kg/L and aromatics ≥ 8.0 vol. %.

>> Blends to be no more than half synthetics by volume.
>> If both percentages > 50 vol. %, then maximum possible FT IPK is 50 vol. %.

Example:
Given batch of JP-8 with density of 0.798 kg/L and aromatics of 13.9 vol. %.

1) Based on JP-8 density, percentage is 49 vol. %.
2) Based on JP-8 aromatics, percentage is 42 vol. %.
3) For this given batch of JP-8, the maximum FT IPK possible in blend is 42 vol. % (lower value).

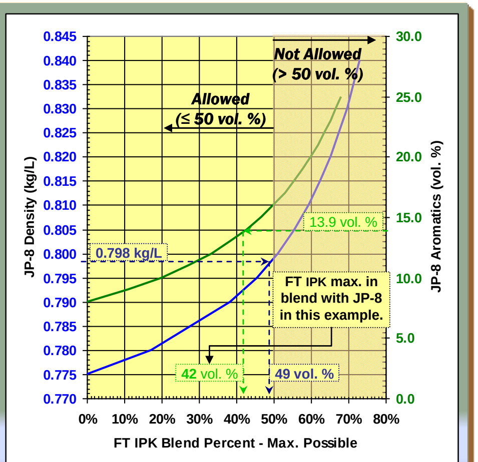
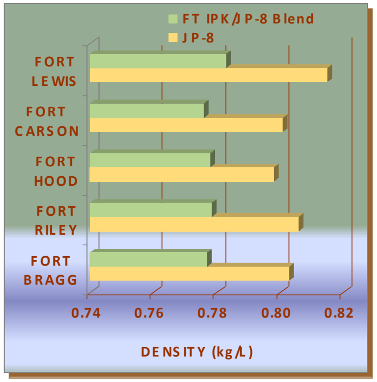
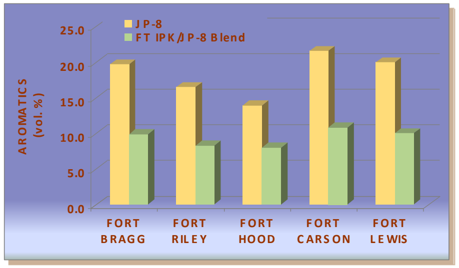


Chart Basis
FT IPK: density = 0.751 kg/L, aromatics = 0.0 vol. %

Curves can be re-plotted to accommodate FT IPK property values differing from those on which this chart is based.

LESS VARIATION IN PROPERTIES FOR SYNTHETIC FUEL BLENDS AS COMPARED TO PETROLEUM-ONLY DERIVED FUEL





– Fischer-Tropsch Iso-Paraffinic (FT IPK) properties based on previously reported data
– JP-8 typical properties based on DESC data for several fuel deliveries during April 2006 – March 2007

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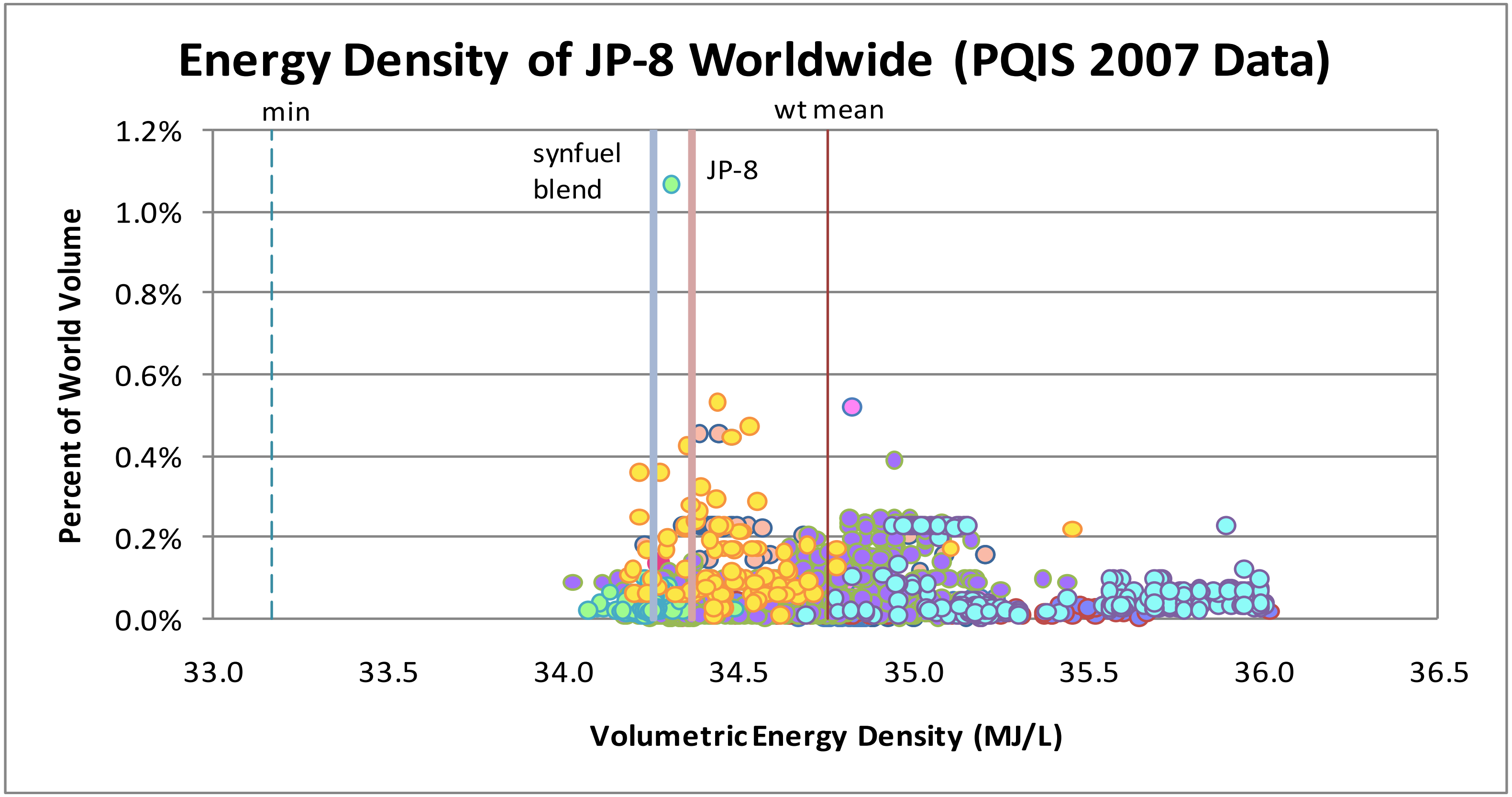
Property Values of Synfuel Blends* Fit Within Range for JP-8

EXAMPLE: Volumetric Energy Density (see chart)

(1) JP-8 batches procured in 2007 worldwide, range and distribution, wt. mean.**

(2) Test fuels, GEP engine evaluation. JP-8 and synfuel blend

(3) Minimum shown is calculated from what is allowed by JP-8 spec. for minimum density and minimum net heat of combustion.

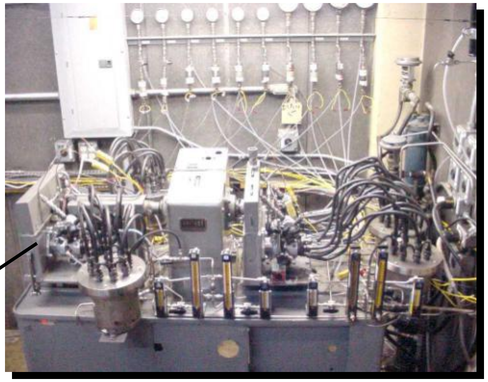


* Synfuel Blends: blends of Fischer-Tropsch Synthetic Paraffinic Kerosene and JP-8 meeting MIL-DTL-83133F(JP-8 spec)

** Calculated values; batches missing data not included

Lubricity Testing
TARDEC F&L Research Facility

- **Bench-top lubricity evaluations**
  - BOCLE, SLBOCLE, and HFRR battery
  - BOCLE indicated improved lubricity of FT fuel treated with CI/LI additive per QPL-25107



- **Rotary fuel injection pump test rig testing**
  - Showed FT SPK with lubricity improved to a level indicative of acceptable field performance
  - Both at min. and max. treat rates per QPL-25017
  - Results documented in **SAE Paper 2004-01-2961**

"Early Demo" – Tactical Generators TARDEC F&L Research Facility

- **Objective:** Operate tactical equipment using 50:50 FT synthetic fuel blend
- **Test Protocol**
  - Three 10 kW generator sets
  - Gen sets "broken-in" using Ultra-Low Sulfur Diesel (ULSD)
  - Gen sets fueling during test, operating cycles (% of total time)
    - Gen sets #1 & # 3
      - 10% – ULSD
      - 45% – JP-8
      - 45% – 50:50 blend of FT SPK:JP-8
    - Gen set # 2
      - 100% – FT SPK
  - Tests conducted for 1000 hrs at 50% load
- **Some Results** (final report in DTIC)
  - No reliability issues encountered
  - Power generation unchanged for all fuel cases
  - Exhaust emission checked; NOx lower using fuel blend than for JP-8

TWV Pilot Field Demo
TARDEC F&L Research Facility

- **Determine effects of using fuel blend in a subset Army legacy ground vehicles**
- **Field demonstration fleet (variety of wheeled vehicles) at Ft. Bliss, TX**
  - (2) M998 HMMWV
  - (9) M925 A2 5-Ton truck
  - (10) M1075 LMTV
  - (10) M1083 A1 FMTV
  - (2) M1089 A1 FMTV
  - (1) M984 A1 HEMTT
  - (1) M978 HEMTT
  - (10) M915 A4 TRAC
  - Control vehicles of the same type, operated on JP-8 will be included
- **Data generation**
  - Monthly fleet performance monitoring and fuel analyses
  - Vehicle fuel injection systems pre-test inspections for operation / fuel leaks
  - Up to 10 fuel injection system (blend fueled vehicles) post-test inspections (or earlier if needed) to check operation / fuel leaks
- **No recordable issues to-date**
- **Field demo expected to finish in July 2009**

RDECOM

Army Fuel Requirements and the JP-8 Specification

TARDEC

- **Army started conversion from diesel fuel to Single Fuel in the Battlefield (SFB) in 1980s, implemented in 1988**
  - Done on “no-harm” premise basis for use of aviation turbine engine fuel in Army equipment typically having compression ignition (CI) engines
- **Army equipment has generally maintained acceptable levels of performance and durability using SFB, but have been some issues**
- **Requirements in diesel fuel specs not in JP-8 spec**
  - Minimum viscosity at 40 C (1.3 mm^2/s, No. 1-D)
    - ➢ Low fuel viscosity could lead to increased wear rates in some types of fuel injectors and injection pumps
  - Minimum Cetane No. (40, No. 1-D and 2-D)
    - ➢ Better cold-starting of CI engines
    - ➢ Better CI engine performance, namely less misfire/combustion instability, for light to medium load operation
  - Army request to add these two requirements, to Table A-1 for FT SPK, during last revision to MIL-DTL-83133F was dismissed, will try again for next revision
- **Different lubricity specification for DF-2 (HFRR) vs. JP-8**

Aviation Alternate Fuels Roadmap

Level 1 / Scenario

May 4, 2009

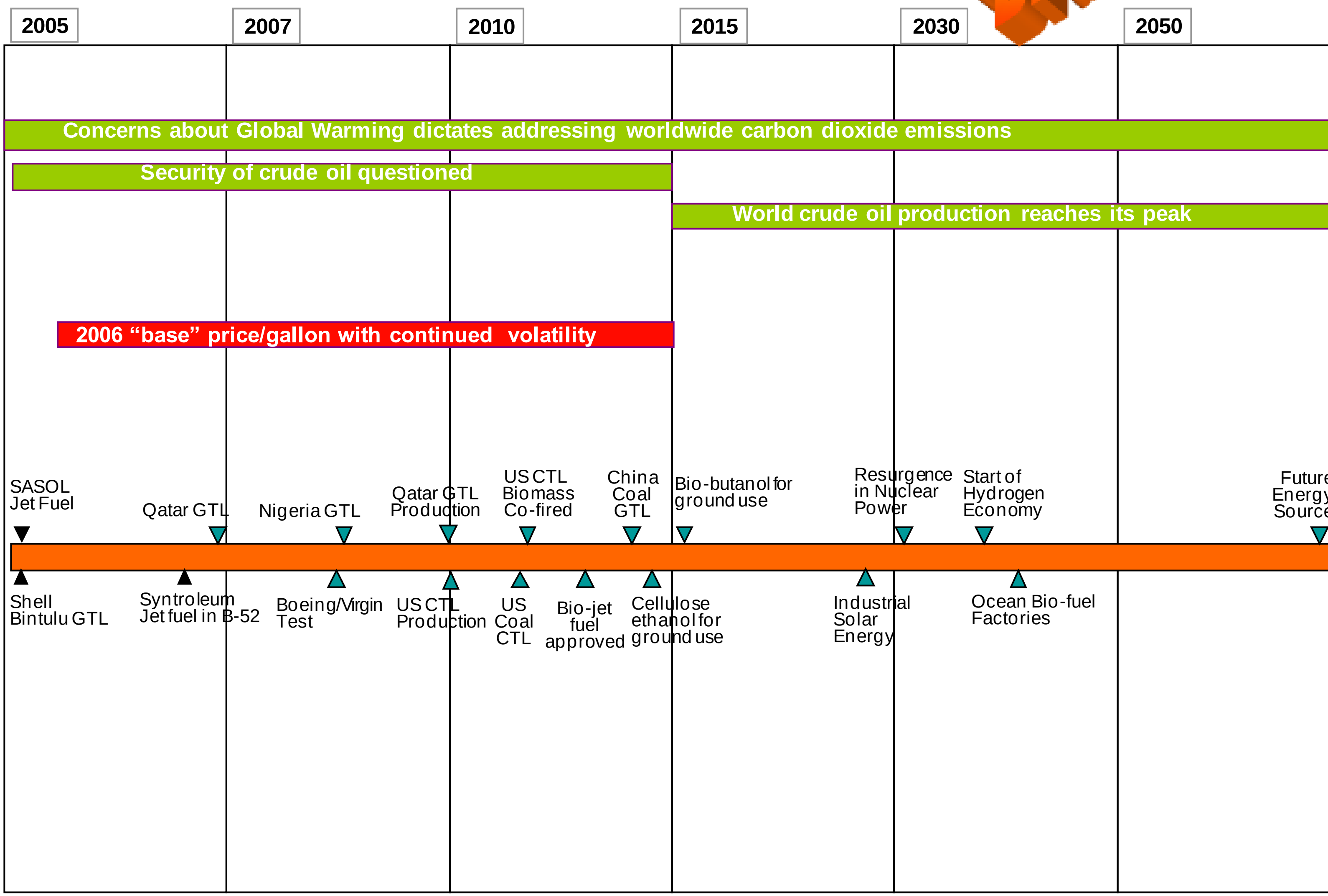
Draft

Category

Market Drivers
Environmental,
Political,
Resources

Anticipated
- Fuel Price
- Availability (% Demand Filled)

Alternative Fuel Products (Volume Anticipated / Required)



Courtesy –
Mark Rumizen, FAA

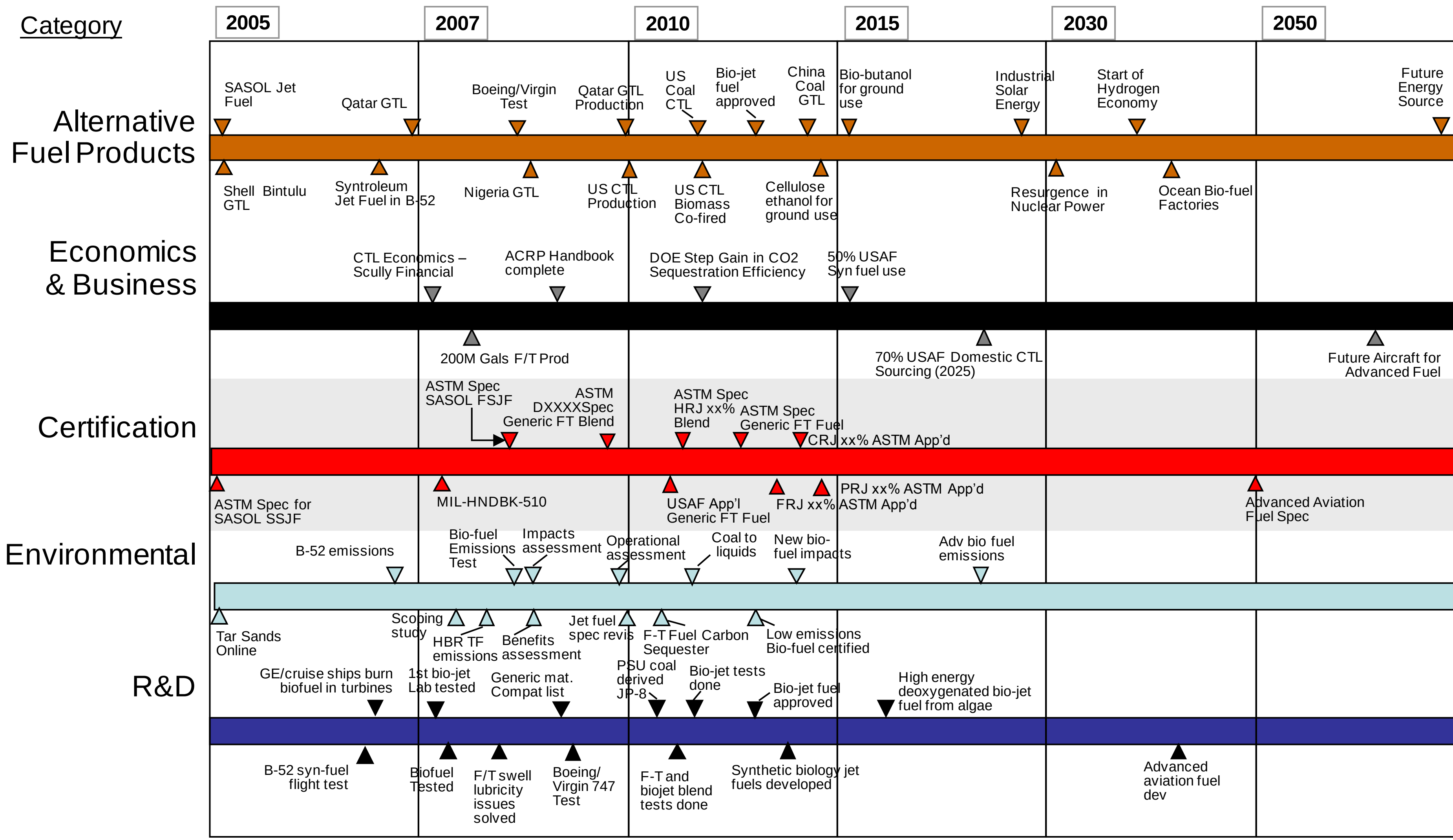
*Fuels produced from seeds and other organic sources such as Soybean Methyl Ester

Status as of July 27, 2007

Aviation Alternate Fuels Roadmap

Level 2 / Scenario 1

May 4, 2009



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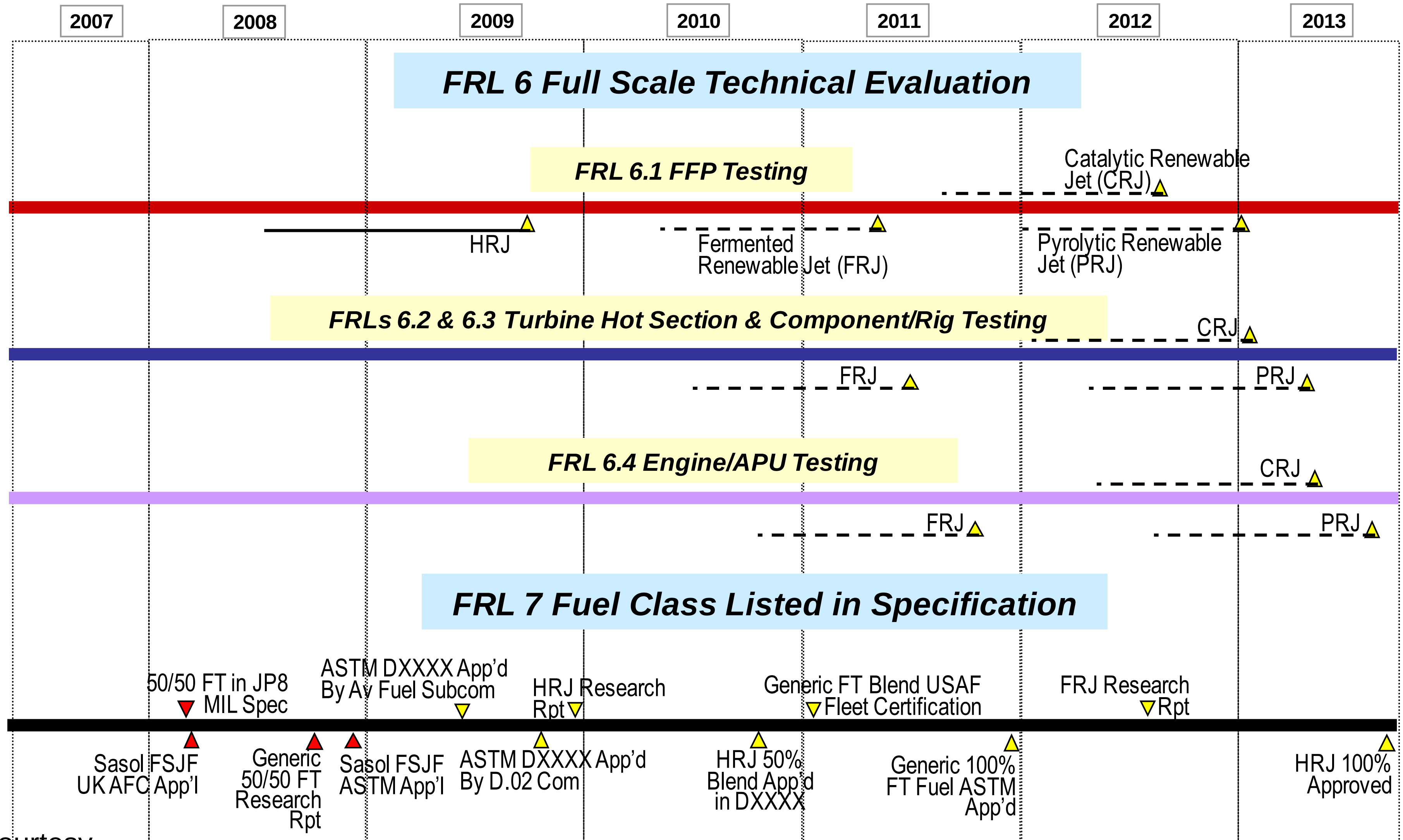
Aviation Alternate Fuels Roadmap

Level 3 / Certification and Qualification

TARDEC

DRAFT

May 4, 2009



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Mark Rumizen, FAA

Fuel Readiness Level (FRL)

Commercial Fuel Readiness Level (FRL) - Alternative Aviation Fuels

FRL	Description	CAAFI Toll Gate	FRL	Description	CAAFI Toll Gate	Fuel Qty	MI
1	Basic Principles Observed and Reported	Feedstock and process basic principles identified					1
2	Technology Concept Formulated	Feedstock and complete process concept identified					2
3	Proof of Concept	Small Fuel Sample Available from Lab Basic Fuel Properties Validated (Thermal Stability/Freezing Point)				500 ml	3
4.1 4.2	Preliminary Technical Evaluation	System Perf. & Integration Studies Entry Criteria/Specification Properties Evaluated (MSDS/D1655/MIL 83133)				10 gal	4
5.1 5.2 5.3 5.4	Process Validation	Laboratory Production Development Subscale Production Demonstrated Scalability of Production Demonstrated Pilot Plant Capability Enabled	6.1 6.2 6.3 6.4	Full-Scale Technical Evaluation	Fit-For-Purpose Prop's Evaluated Turbine Hot Section Component/Rig/Emissions Testing Engine/APU Testing	80 gal 4K gal 20K gal 225K gal	5 6 7 8
			6.5				
			7	Fuel Approval	Fuel Class/Type Listed in Int'l Fuel Standards		
8	Commercialization Validated	Business Model Validated for Production Go-Ahead Airline/Military Purchase Agreements					
9	Production Capability Established	Full Scale Plant Operational					9-1

see next slide for rest of chart

Mark Rumizen / Marty Bradley
January 23, 2009

Legend:	R & D	Certification/Qualification	Business & Economics

Courtesy –
Mark Rumizen, FAA

Fuel Readiness Level (FRL)

Slide 2 of 2

Commercial Fuel Readiness Level (FRL) - Alternative Aviation Fuels

	FRL	Description	CAAFI Toll Gate	Fuel Qty	MRL	USAF TRL
nciples					1	
s concept					2	
om Lab ted Point)				500 ml	3	1. Basic Fuel Properties Observed and Reported
lies perties IL 83133)				10 gal	4	2. Fuel Specification Properties
ment ted nstrated	6.1 6.2 6.3 6.4	Full-Scale Technical Evaluation	Fit-For-Purpose Prop's Evaluated Turbine Hot Section Component/Rig/Emissions Testing Engine/APU Testing	80 gal 4K gal 20K gal 225K gal	5 6 7 8	3. Fit for Purpose 4. Extended Lab Fuel Property Test 5. Component Rig Testing 6. Small Engine Testing
	6.5					7. Pathfinder
	7	Fuel Approval	Fuel Class/Type Listed in Int'l Fuel Standards			8. Validation/Certification 9. Field Service Evaluations
roduction reements						
					9-10	

see previous slide for rest of chart

Legend:	R & D	Certification/Qualification	Business & Economics

Mark Rumizen / Marty Bradley
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Courtesy –
Mark Rumizen, FAA